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ON THE POSSIBILITY OF NUCLEAR REACTOR USE FOR DIRECT MEASUREMENTS IN SPACE OF nn-SCATTERING CROSS-SECTION

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ON THE POSSIBILITY OF NUCLEAR REACTOR UTILIZATION FOR DIRECT MEASUREMENTS IN SPACE OF THE nn-SCATTERING CROSS SECTION

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SUMMARY

A computation is performed of the experiment for direct measurement of the nn - scattering cross-section in the singlet state. A pulse nuclear reactor, with a negative temperature factor and location in space at an altitude of 400 — 500 km is suggested. It is shown that the scattering length may be determined with an error of ± 10%.

* * *

1. - A precise knowledge of neutron over neutron scattering parameters is essential first of all from the viewpoint of direct verification of the hypothesis of the charge-invariant of nuclear forces [1]. Experiments on neutron scattering by protons provide with a sufficiently high degree of precision the parameters characterizing the singlet state of the system neutron-proton [2]. As to the experiments on neutron-neutron scattering, direct measuremen of scattering parameters could not be realized to-date on account of low densities of free neutrons attainable at present time ($\sim 10^{10}$ n/cm^3). When discussing the possibility of direct investigation of the nn-scattering process, one must bear in mind that the experiments with neutrons, whose energy is $\lesssim$ 15 Mev, provide information on the forces acting between neutrons in the singlet S-state only. Proposed in the present work is an experiment allowing to measure directly the cross-section of nn-interaction in the S-state.

* O VAZMOZHNOSTI ISPOL'ZOVANIYA YADERNOGO REAKTORA V KOSMICHESKOM PROSTRANSTVE DLYA PRYAMOGO IZMERENIYA SECHENIYA nn - RASSEYANIYA.

2. - The scheme of the experiment consists in the following: Assume that in vacuum space of sufficiently great dimensions, such that one might neglect the scattering from "walls", a neutron burst is produced, such that during its duration τ, Q neutrons are emitted. If the detector is shielded from "direct" neutrons, it is evident that only neutrons, scattered by one another, can penetrate in it. (See Fig.1)

We assume also that the space is made vacuum to a degree, whereby the scattering from nuclei of the surrounding medium is not great. Such a high vacuum can be assured by conducting the experiment in space at an altitude of 400 - 500 km, where the source of neutron may, for a brief time (flight along a ballistic curve), may be supplied with the aid of a geophysical rocket. A pulse reactor may serve as the source of neutrons, and an He^3- filled ionization chamber could serve as the detector.

3.- The expression for the number of pulses J, provided by the chamber in the course of one burst, may be written in the form

$$J = \varkappa(\tau) Q^2 \bar{\sigma}_{nn} s \bar{\varepsilon}_{\text{вмп}}. \qquad (1) \quad *)$$

Here Q is the number of neutrons emitted by the reactor during the burst, τ is the duration of the neutron burst, $\bar{\sigma}_{nn}$ is the scattering cross-section of neutron by neutron, averaged by the spectrum of colliding neutrons, s is the cross-section area of the ionization chamber, $\bar{\varepsilon}$ is the neutron detector efficiency, averaged by the spectrum of neutrons, incident upon the detector.

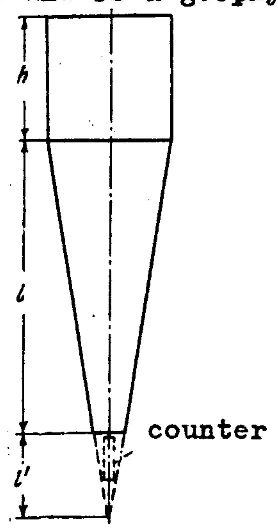

Fig. 1

h — height of the reactor
l — thickness of the shield

The coefficient $\varkappa(\tau)$ depends on the energetic angular distribution of neutrons flying from the reactor, on the angular distribution of neutron scattering, and also on the geometry of the installation and the duration of the proton burst. In the general case we may show that

$$\varkappa(\tau) = \int dV \int d\sigma_1 \int d\sigma_2 \int_0^\infty dv_1 \int_0^\infty dv_2 \int_{-\infty}^\infty dt \frac{S(\mathbf{r}_{1s}, \Omega_1, v_1, t - R_1/v_1)}{R_1^2 R_2^2 v_1 v_2} \times$$
$$\times \frac{S(\mathbf{r}_{2s}, \Omega_2, v_2, t - R_2/v_2) v_{\text{отн}} \sigma_{nn}(v_{\text{отн}}) g(\mu, v_s)}{R^2}, \qquad (2)$$

*) [see next page]

where $d\sigma_1, d\sigma_2$ are elements of the area of the emitting surface with radius-vectors $\mathbf{r}_{1s}, \mathbf{r}_{2s}$; dV is the element of volume in which neutron interaction takes place with velocities v_1 and v_2. The function $S(\mathbf{r}_s, \Omega, v, t)$ is the distribution of the number of neutrons emitted per unit of time along the emitting surface, directions, velocities and time, normalized on the unity. The remaining denotations in (2) have the following sense :

$$R = |\mathbf{r}_g - \mathbf{r}|, \quad R_1 = |\mathbf{r}_{1s} - \mathbf{r}|, \quad R_2 = |\mathbf{r}_{2s} - \mathbf{r}|;$$

$$v_{\text{отн}} = |v_1\Omega_1 - v_2\Omega_2|, \quad \mu = \frac{(\mathbf{l}\mathbf{v}_e)}{v_e}, \quad \mathbf{l} = \frac{\mathbf{r}_g - \mathbf{r}}{R}, \quad v_e = \frac{v_1\Omega_1 + v_2\Omega_2}{2}, \quad *)$$

$\mathbf{r}_g$ is the radius-vector of the detector; $g(\mu, v_e)$, is the probability, computed per unit of the solid angle, that one of the colliding neutrons will be scattered in the direction constituting the angle $\Theta = \arccos\mu$ with the direction $\mathbf{v}_e$.

The multiple integral (2) was computed by the Monte-Carlo method using an electronic computer. It was then assumed that the distribution of sources S by cylinder height has the shape of cosine curve; the angular distribution of escaping neutrons corresponds to the Fermi distribution; the pulse configuration as a function of time is Gaussian; the angular distribution of scattered neutrons

Calculations have shown that in the regions of $10^2 - 10^3$ pulse widths the coefficient $\varkappa$ is inversely proportional to τ and decreases with the increase in hardness of the spectrum of interacting neutrons. The numerical estimates of the pulse width τ for the reactor with negative temperature reactivity factor were conducted by the formula

$$\tau = 3{,}5\frac{l}{\delta k_0}, \qquad (3)$$

where l is the lifetime of prompt neutrons in the reactor (the expression (3) is obtained without taking into account the lagging neutrons), δk_0 is the promt jump of reactivity. The quantity δk_0 is in its turn expressed by the correlation :

$$\delta k_0 = \frac{|\alpha|}{2}(T_{max} - T_0). \qquad (4)$$

*)[The denotation отн stands for 'relative'
" " имп " for "pulse".]

Here $|\alpha|$ is the temperature factor of reactivity, T_0 is the initial temperature of the active zone, T_{max} is the maximum acceptable temperature.

4. - On the basis of correlations (1) — (4) various types of reactors were analyzed, including the homogenous - water-bare reactor and the Godiva-type zirconium hybride-beryllium-reflected reactor. The choice of the the type of reactor was determined mainly by maximum effect and compactness requirements. Analysis has shown the latter to be the most acceptable type. Its characteristics, obtained as a result of multigroup calculation with utilization of 18 groups of neutrons, are as follows: the active zone is a cylinder of 30 x 30 cm^2 dimensions; its thickness is of 10 cm, the fuel is U^{235} with 75% enrichment; $\rho_H / \rho_U = 500$; $K_\infty = 1{,}52$. According to data of [3], for reactors of such a type $\alpha = -4 \cdot 10^{-4}$ per 1° C, $l = 50$ mk sec, $T_{max} = 700^\circ$, $T_0 = 20^\circ$. The quantity Q was estimated by the heating of the active zone. At the same time the following values of heat capacity and specific weight were adopted for ZrH :

$$C = 0.08 \text{ kcal / kg } ^\circ C \quad \text{at} \quad T = 25^\circ C,$$
$$C = 0.16 \text{ kcal / kg} ^\circ C \quad \text{at} \quad T = 500^\circ C,$$
$$p = 5 \text{ g / cm}^3.$$

The neutron escape was taken into account by the factor $(K_\infty - 1) / K_\infty$. The neutron absorption in the reflector can be neglected. Taking into account that neutrons escaping through one of reactor's faces are waisted, we obtained for Q the value $Q = 8.6 \cdot 10^{17}$ n.

For the geometry represented in Fig. 1 at $l = 200$ cm, with a chamber 35 cm long and 3 cm in diameter, the calculations gave the coefficient the value $\varkappa = 0.66 \cdot 10^{-37}$ (on 1 bn). The effectiveness of the chamber with He^3 (pressure of 20 atm), averaged by the neutron spectrum emerging from the reflector, was found to be $\sim 32\%$.

For the estimate of the effect, the value $\bar{\sigma}_{nn} = 70$ bn, equal to that of the singlet cross-section of np - interaction, was adopted. In computing the effect the requirement was found to accounting for energy liberation on lagging neutrons (being about 50 percent of the total energy liberation). Assuming that measures were taken to suppressing the lagging neutrons (which is practically realizable), we obtain from formula (1) $J \approx 114$ pulse.

5. - In the computations conducted the estimate of background is essential. Four background sources were taken into account.

a) Background from neutrons and γ -rays of the reactor, of which the level is determined by the height l of the shielding cone. Calculations have shown that the shielding, made of borated paraffin and lead with 200 cm thickness is sufficient to lower the reactor background down to 1 – 2% level.

b) Background from neutrons of cosmic space and charged particles. Its estimate was conducted on the basis of works [4, 5]; it gave a value not exceeding 1 — 1.5%.

c) Background from reactor neutron scattering by particles present in the interplanetary space (according to literature data [6], the density of particles in the 400 – 500 km altitude range constitutes $\sim 10^8$ part. / cm^3.

d) Background from reactor neutron scattering by air molecules, adsorbed by the surface of the rocket and then vaporized in the discharged interplanetary space.

The estimates of backgrounds c) and d) was effected by formulas analogous to that for the calculation of the factor $\varkappa$. Numerical computations have shown that the background c) constitutes $\sim 15\%$, the background d) — near 0.5% (it was assumed that 10 molecular layers of nitrogen are adsorbed on the surface). The aggregate background constitutes therefore $\sim 18\%$ (it should be noted that the estimate conducted is maximum). This value may be considered as acceptable, particularly if we take into account that the backgrounds a) and b) may be measured directly in the course of the experiment; the backgrounds c) and d) may be indirectly taken into account by way of measurement of particle density near the rocket and subsequent calculation.

6. - At reasonable assumptions relative to measurement errors for the quantities entering in formula (1), it is not difficult to see that the aggregate relative error $\bar{\sigma}_{nn}$ will constitute $\pm 20\%$. Considering the dependence of the phase shift of the S-wave on energy [7] and assuming that the parameters of the neutron-neutron interaction will be of same order of magnitude, as the interaction neutron-proton, it is possible to reach the conclusion that at average energy of the acting neutron spectrum ~ 1 kev, as in our case, and for a 20% measurement error of $\bar{\sigma}_{nn}$,

the contributions of the quadratic as well as linear terms to the value of the cross-section are immaterial. Therefore, the correlation

$$\sigma_{nn} = 4\pi a^2, \qquad (5)$$

where ● is the length of nn-scattering, is fulfilled with good precision. As follows from (5), the relative measurement error of the scattering length will constitute ± 10%, which is not worse than the error attained in the best indirect experiments [8] for the investigation of nn-scattering.

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*** THE END ***

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REFERENCES

[1].- M. J. MORAVCSIK.- Phys.Rev., 136, 313, 624, 1964.

[2].- M. H. McGREGOR, M. J. MORAVCSIK, N. P. STAPP.- Ann.Rev.Nucl.Sci. 10, 291, 1960.

[3].- I. P. BEALL.- Trans.Amer.Nucl.Soc. 4, 1, 111, 1961.

[4].- S. N. VERNOV, N. L. GRIGOROV, Yu. I. LOGACHEV et al.- ISZ 'AES), 1 , 5, 1958.

[5].- R. HAYMES, S. KORIFF.- Phys.Rev. 120, 1460, 1960.
R. HAYMES.- J. Geophys. Res. 69, 841, 1964.

[6].- Ya. L. AL'PERT. UFN, 3, 369, 1960.
V. G. KURT.- UFN, 2, 249, 1963.

[7].- H. A. BETHE.- Phys. Rev. 76, 38, 1949.

[8].- V. K. VOYTOVETSKIY, I. L. KORSUNSKIY. Yu. F. PAZHIN.- ZhETF, 47, 1612, 1964.